Roadmap to Water-and Energy-Efficient and Cost-Effective Residential Hot Water Distribution Systems

1) Collect and review existing information.
    - Create and maintain a project website
    - Add publications to this website
    - Include annotated bibliography on key studies and reports
    - Review the reports to assist in research issues and work plan
    - Has research already been done that addresses this question? (For example, ground source heat pumps, district heating systems, pipe insulation manufacturers.)

2) Determine the extent of this problem.
    a. Put boundaries around the problem.
        - Water, energy, sewer, other environmental
        - Water heater, distribution system, fixtures
        - Health and safety
        - Single family, multifamily, manufactured homes
        - Low-rise, high rise
        - Existing, new construction
        - US, North America, other countries
    b. Size of problem
        - How much of the hot water use will be impacted by changes in the distribution system?
        - Total costs of the problem
        - Total costs of the possible solutions
        - Is this problem worth solving?

3) Surveys
    a. What's being built?
        - Builders, plumbers, architects, engineers, building inspectors
        - What are the plumbing systems that are being installed?
        - What are the trends in new construction?
        - What are the costs of the systems being installed?
    b. How well does it work?
        - Existing homeowners and renters
        - What do customers think of the systems that they have?

4) Determine how hot water is used (and wasted)
    - Take field measurements in existing homes throughout the country to see how hot water is currently being used.
    - Build on the work already done by Aquacraft, ASHRAE and others.
    - Make sure that measurements support the agreed to boundaries.
    - Count what's worth counting

a. Develop a data acquisition system to measure hot water consumption and patterns of use. This task is to develop the instrumentation and distributed data acquisition system (DAQ) for hot water flow and temperature characterization in the field. This should build on previous work done by others. The DAQ could employ wireless remote non-intrusive sensors so that installation into houses can be done quickly. Assess the rapidly developing wireless sensing and networking technologies before making a decision. Steps include DAQ development followed by production of systems for use in the field.

b. Conduct field measurements on a large number of "real-world" houses. Determine appropriate sample size. Characterize each house by occupant number, ages, types of fixtures and appliances (e.g. showers, washing machines and plumbing system layout). For each house, measurements of hot/cold flows, flow duration, timing, and delivery temperatures at each fixture will be done using the DAS technology developed in item 2, above.

c. Analyze data by draws to determine type of draw (e.g. bath), total water in draw, mixed temperature at point of use, flow of hot water, etc.

d. Analyze the impact of varying occupant behavior on different hot water distribution systems.

e. Perform a behavior analysis to determine how customers change how they use water if hot is readily available at fixture.

5) Develop a hot water distribution simulation model.
   - Compare the existing flow and temperature simulation models to analyze the performance of distribution systems systems. Build on work already done by Davis Energy Group, ORNL and NAHB Research.
   - Develop a model that draws upon the strengths of all the existing models [competition to match lab & field data.]
   - Does the model need to include pressure drop, face velocity, turbulence?

6) Conduct controlled laboratory experiments.
   - Determine the essential parameters of hot water distribution systems for use in simulation models, building standards and incentive programs.
   - Determine how to bound the testing to limit the time and cost of this exercise. Limit testing to smallest amount of data. Maybe move early in roadmap.

   a. Perform experiments in the laboratory according to an agreed to version of Table 1 Laboratory Testing Parameters for Hot Water Distribution Systems. This represents a large number of runs. Phase the research, starting with the simple cases and progressively increasing the complexity, including actual piping networks.

Table 1 Laboratory Testing Parameters for Hot Water Distribution Systems

Pipe	Diameter	Layouts	Surroundings	Draw Patterns
Copper PEX CPVC	3/8” ½” ¾” 1” 1.5” 2”	Straight Trunk & branch Parallel Re-circulation • Thermosyphon • Continuous • Timer • Temperature • Time & Temp • Demand	Still & Moving air Dry & Wet sand Dry & Wet Soil Dry & Wet Gravel concrete Insulated Un-insulated Range of temperature	Range of Flows rates Durations of each draw Times between draws Range of hot water supply temperatures Operating pressures

b. Leverage work already done by National Association of Home Builders Research Center for the tree and parallel configurations for 2-story layouts. Take temperature, flow, time, water, and energy data.

c. Validate and calibrate the hot water distribution system simulation model(s) using the test results. Start with the simple cases, and then go to those that are more complex. Use the validation to assist in reducing the number of laboratory tests. Use the laboratory testing to calibrate the hot water distribution model for different piping networks.

7) Determine the best configuration and layout.
   - Use the model to predict energy and water savings for many different piping configurations. Exercise the now calibrated model through analytic studies over a wide range of piping layouts, distances, water consumption patterns, etc. to determine best configurations and things to avoid.
   - Test the best theoretical configurations in actual homes.
     a. Use the DAS and surveys to assess actual performance and customer satisfaction
   - Use these results to recalibrate the model if necessary.

8) Provide installation guidelines.
   - Many builders have problems today that they are trying to solve. They are looking for reasonable, if not necessarily optimal solutions. Manufacturers of possible alternatives are trying to get their solutions implemented and there is a fair amount of confusion in the marketplace. Some solutions save water, but at the expense of energy. Ideally we are looking for solutions that save both.

- At the start of the project
    a. Provide installation guidelines based on the best currently available information. It is for builders and plumbers to start using tomorrow. It may not be the optimum, but it's a clear statement of what we know today about current best practices
- At the end of the project
    a. Provide installation guidelines based on the results of the research.

9) Develop and implement market useful tools.
    - Conduct demonstrations of the best configurations in various markets around the country.
    - Produce and package information from the model studies that can be used by industry and water and energy utilities to speed hot water delivery to end-uses while at the same time reducing energy and water consumption.
    - Groups such as the American Society of Plumbing Engineers, NAHB, Heating and Piping Magazine, and other trade associations should become involved with the findings.

10) Develop voluntary incentive programs
    - Work with utilities, government agencies and other organizations to encourage voluntary implementation of high performing hot water distribution systems. This includes Energy Star, Green Building, LEED, HERS, and maybe Water Star?

11) Update building and plumbing codes
    - Work with ASHRAE, ASME, ASPE, IAPMO and ICC and CEC and others to assure that plumbing and energy codes reflect the new knowledge that is developed in this project.

12) Determine who needs to be involved and at which stages

- Funders
    a. Federal
    b. State
    c. International
    d. Local
- Researchers
- Implementers
    a. Architects
    b. Engineers
    c. Builders
    d. Plumbers
    e. Inspectors
    f. Occupants
- Utilities (water, energy, sewer)
- Associations
- Code bodies